VECTOR FIELD VISUALIZATION

Course Notes

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June 1995

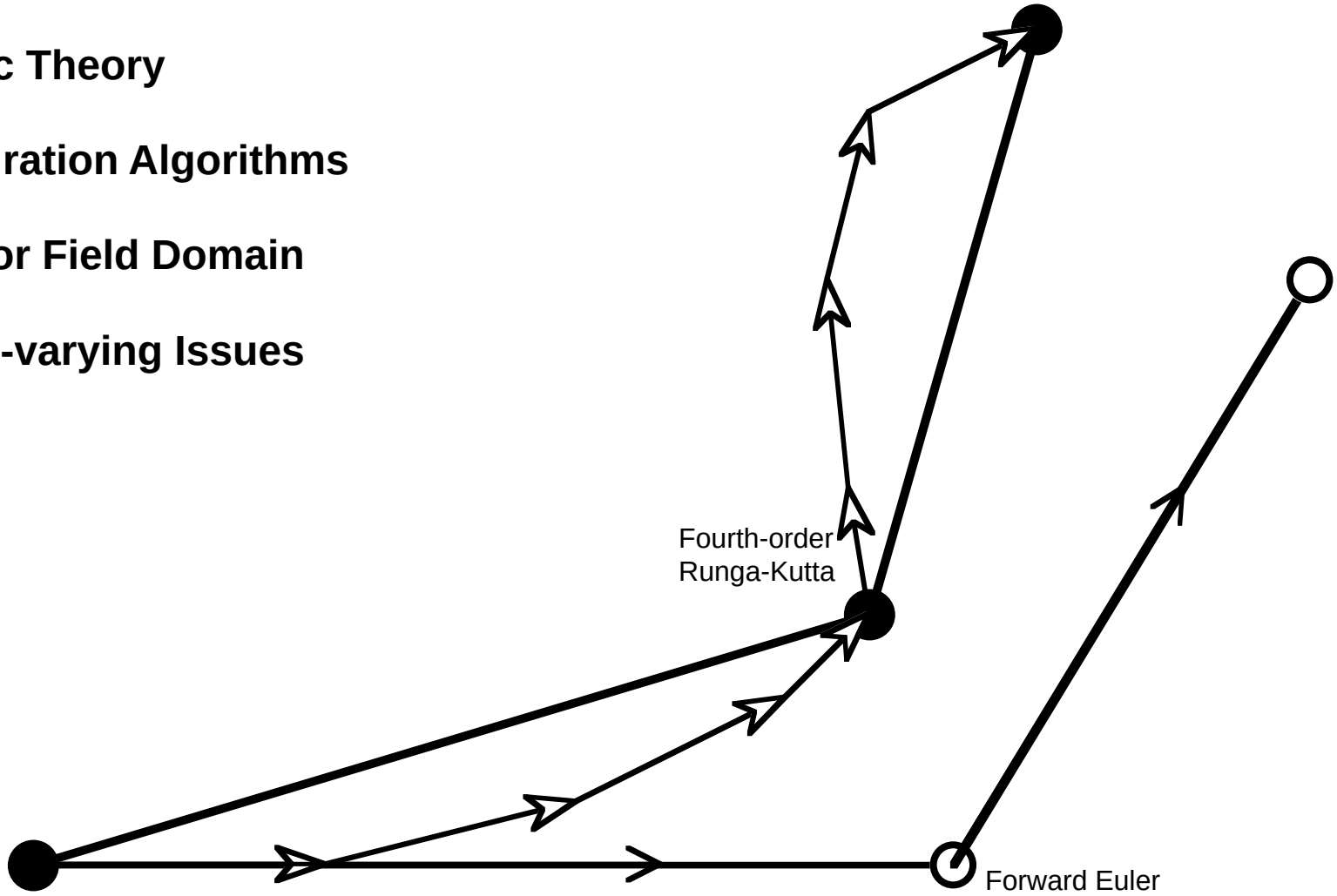
UCRL-MI-120622 Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Outline

- **Advection Techniques**
  - Advection algorithms and issues
  - Streamlines, pathline and streaklines
  - Particle systems
  - Ribbons and tubes
  - Stream surfaces
  - Streamballs
  - Flow volumes
- **Global Techniques**
  - Hedgehogs
  - Vector Filter Kernel for Volume Rendering
  - Line Integral Convolution (LIC)
  - Line Bundles
  - Textured Splats
- **Classification Techniques**
  - Critical point determination
  - Vortex core representations
  - Skin-friction representation
- **Summary / Comparisons**

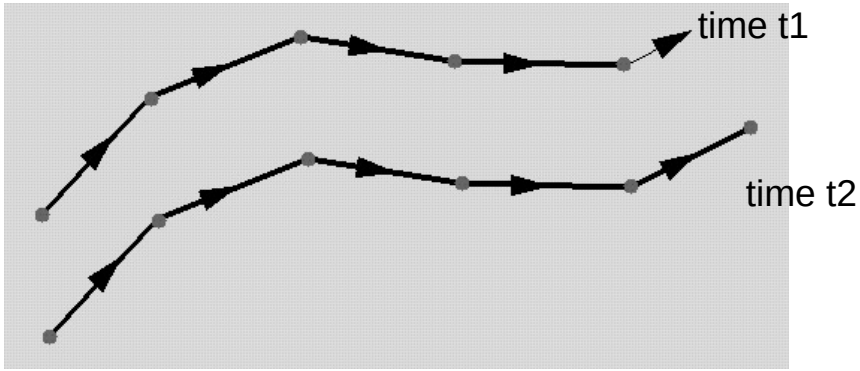
Advection Techniques

- **Basic Theory**
- **Integration Algorithms**
- **Vector Field Domain**
- **Time-varying Issues**

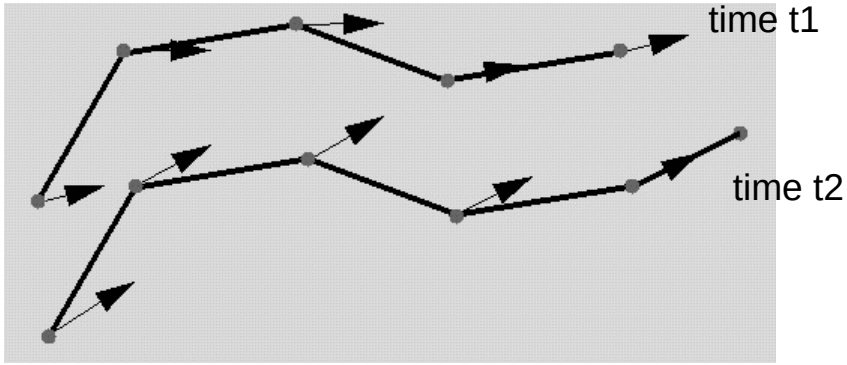


Streamlines, Pathlines, Streaklines

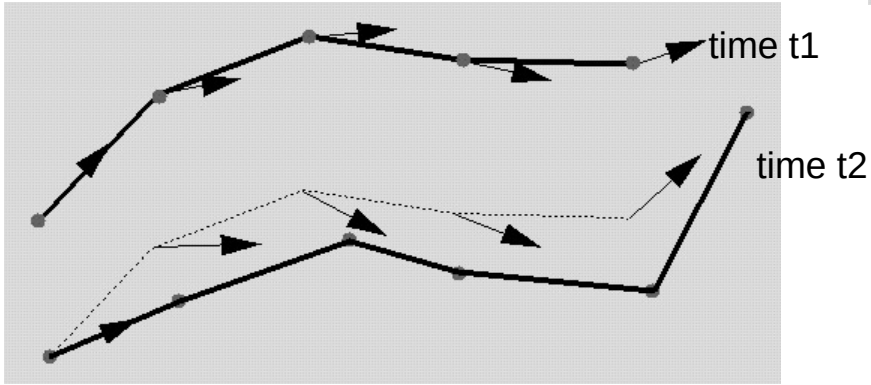
- **Streamlines**



Pathlines



Streaklines



Streamlines

- **Many streamlines can give an overall feel for the vector field.**

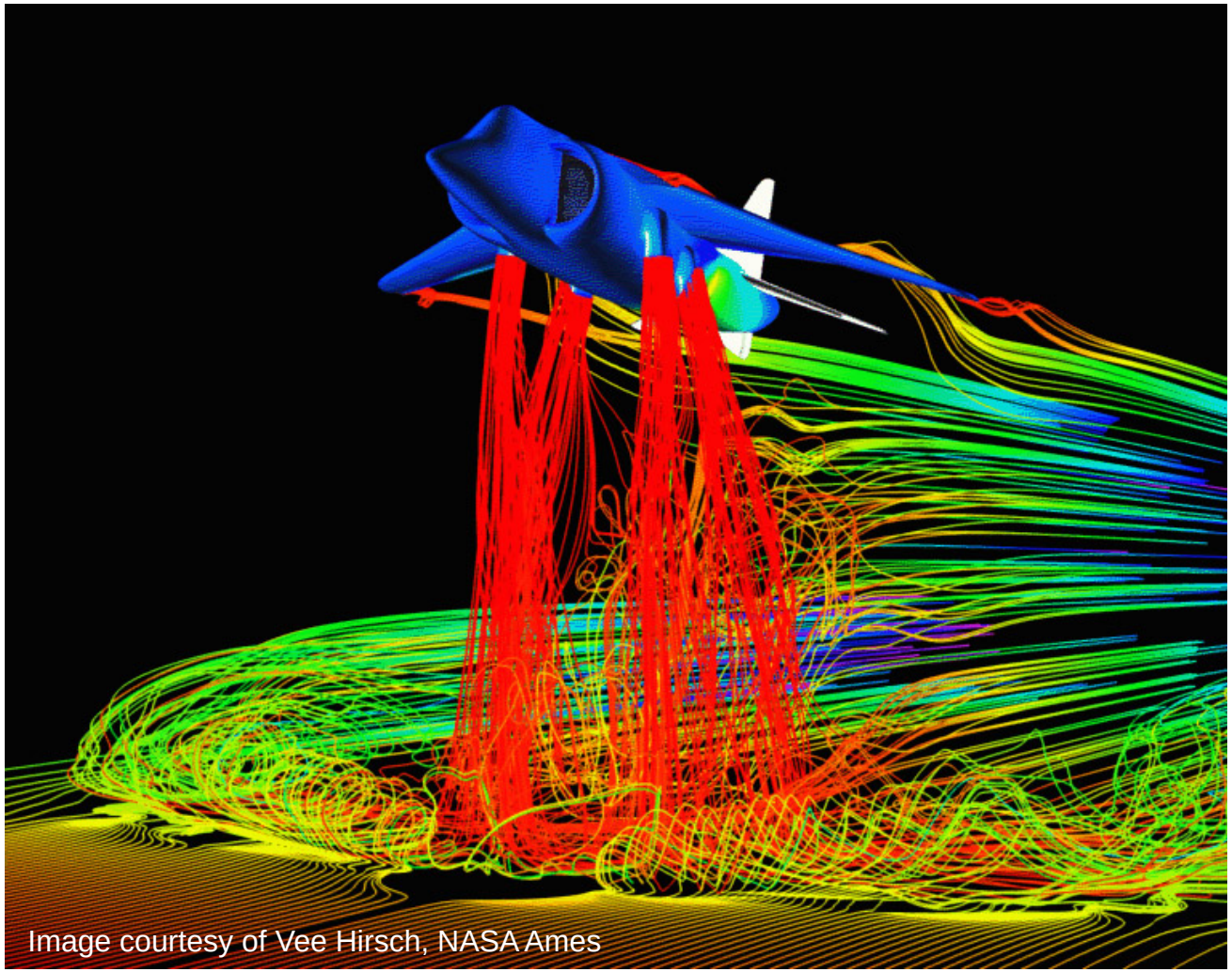


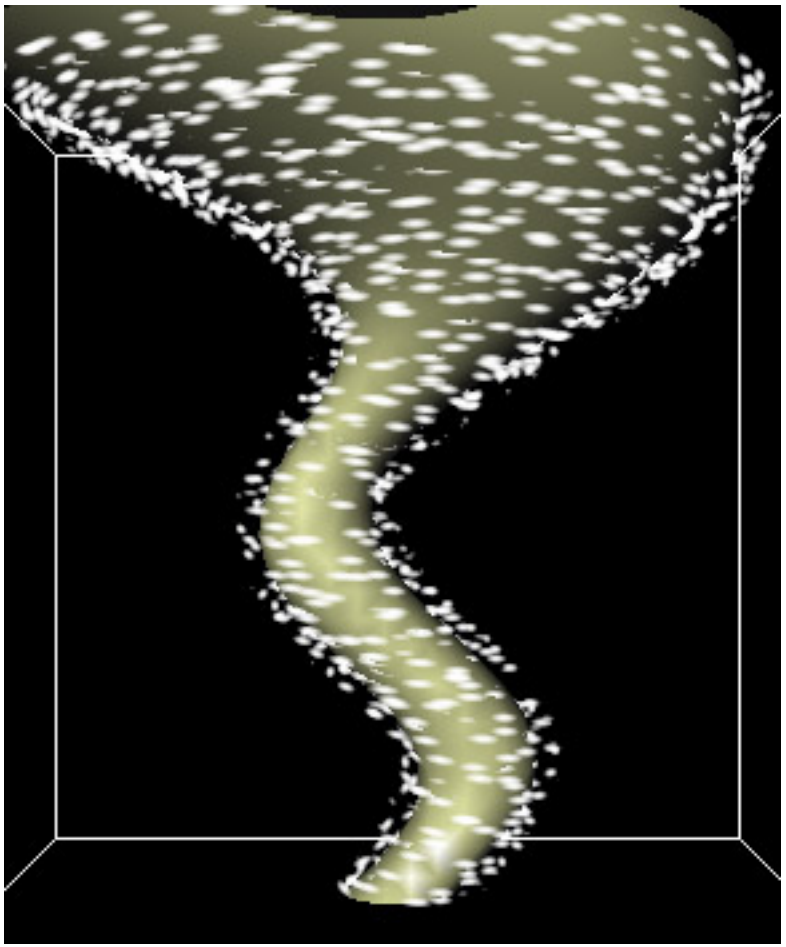
Image courtesy of Vee Hirsch, NASA Ames

Particle Systems

- **Reeves introduced particle systems for representing fuzzy objects such as waterfalls, grass and fire.**

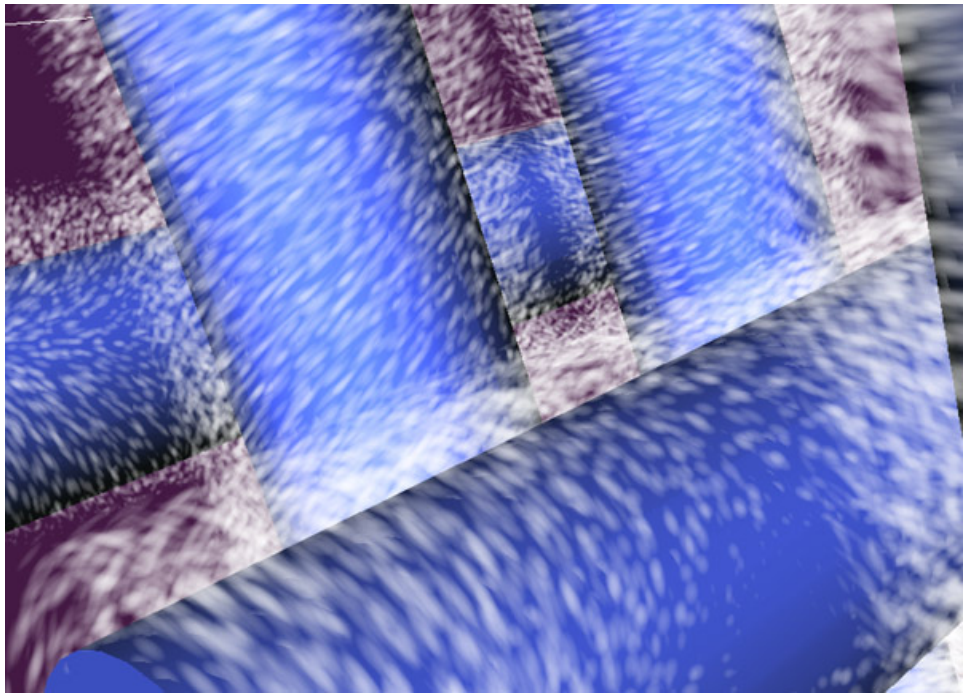
- **van Wijk uses particles with motion blur, depth of field and hidden particles to animate particles on stream surfaces.**

- **Max constrains particles to be within a tolerance of a contour surface.**



Particle Systems — Max

- Max's particles are rendered using a small texture mapped dot that is stretch in the flow direction.
- If all of the dots are the same color, no sorting is required.
- New particles fade in as they approach the surface and fade out as they depart.



Ribbons and Tubes

- **Ribbons can be constructed using 2 or 3 particle advections per segment.**
- **Ribbons can also be calculated using the curl of the vector field about a streamline.**
- **Ribbons and Tubes provided an added depth cue with lighting.**
- **Schroeder describes a stream polygon for multivariate visualization**

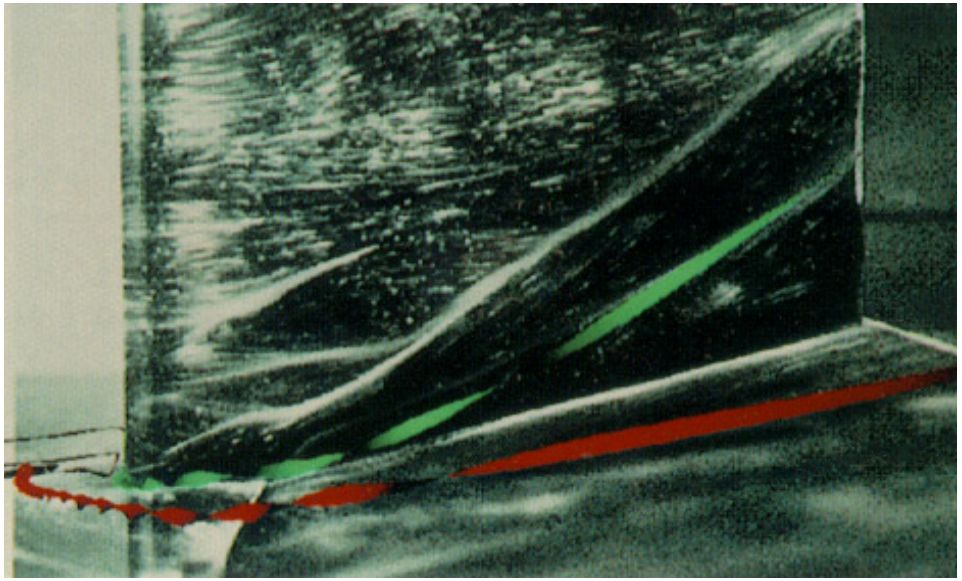
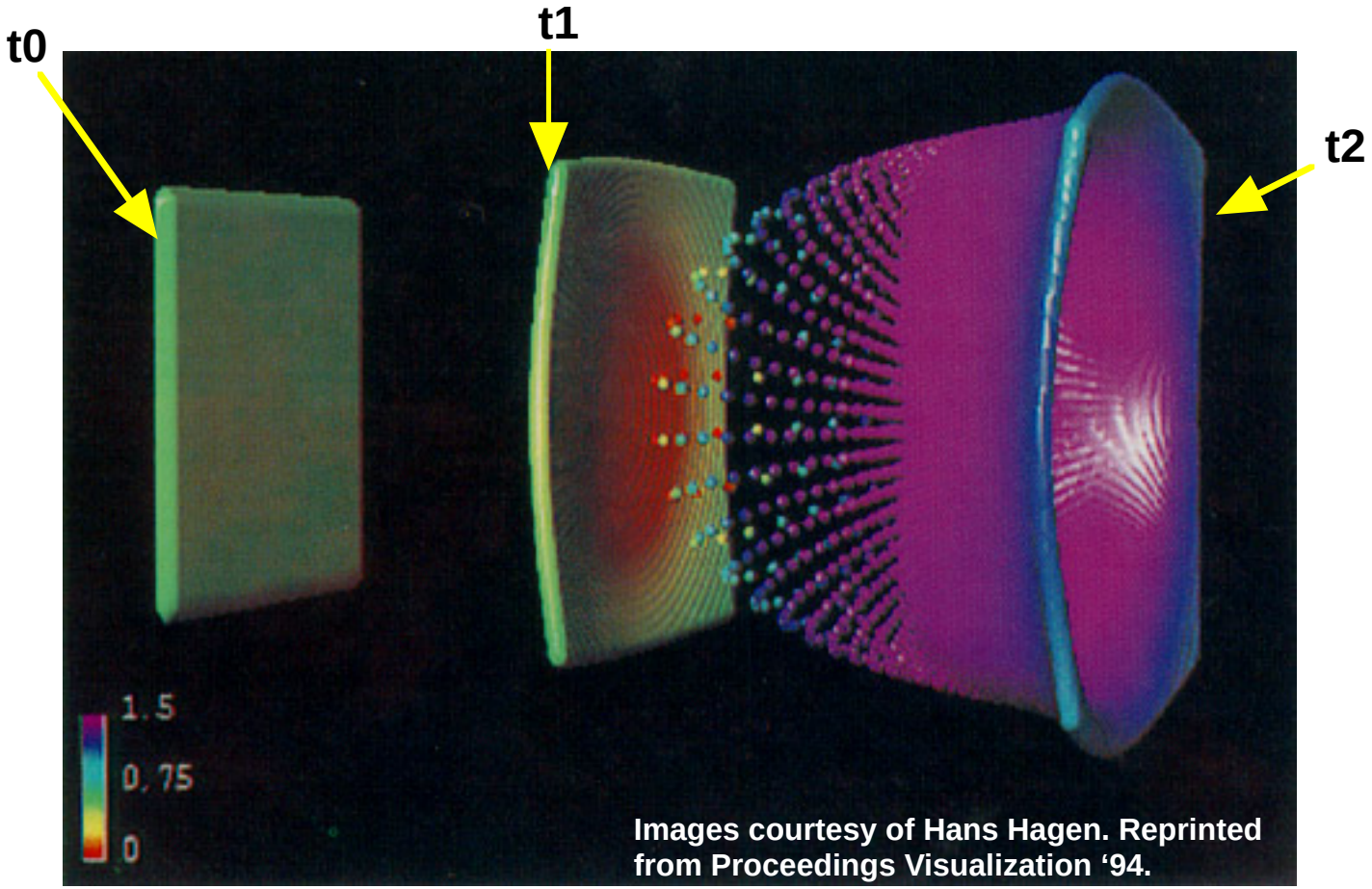


Image courtesy of H. Pagendarm, DLR.

Time lines

- **Timelines or time surfaces can show the evolution of a flow.**



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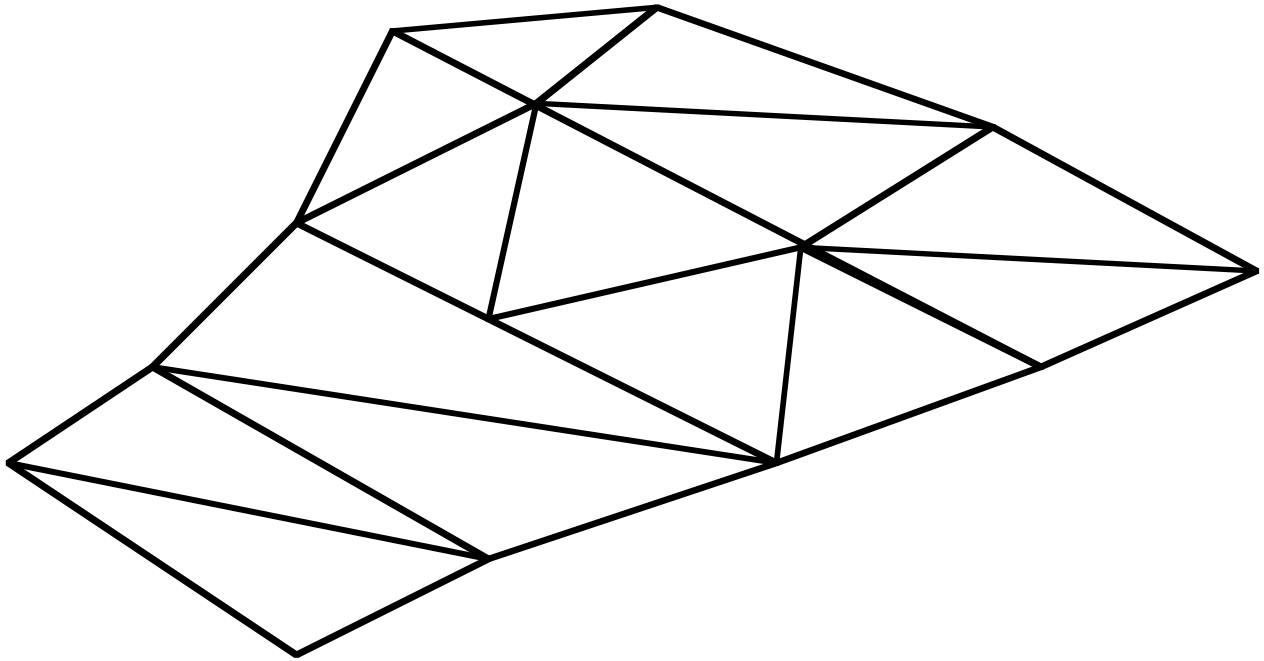
Stream Surface — Explicit

- **Stream Surfaces can be generated explicitly as outlined by Hulquist:**
  - **Start with segmented curve**
  - **Advect each vertex forward**
  - **If adjacent vertices diverge, add new vertices**
  - **If adjacent vertices converge, merge the vertices**
  - **If too much divergence, let the surface split and form a tear.**

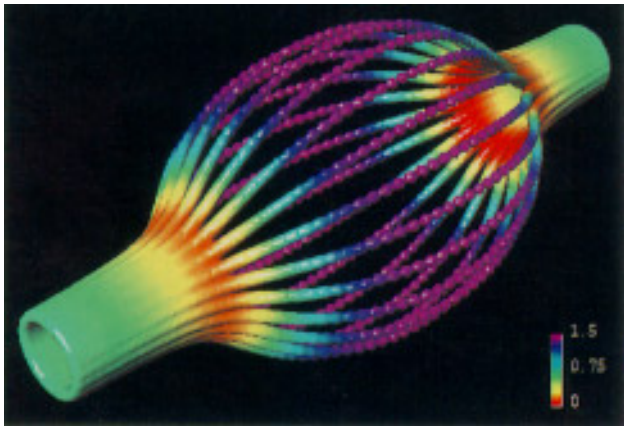


Stream Surface — Implicit

- **Stream Surfaces can also be generated implicitly as outline by van Wijk:**
  - **Place a continous function on the inlet's of a flow simulation.**
  - **For each sample point, trace backwards to inlet**
  - **The value at the inlet intersected with the streamline is used to generate a function f(x,y,z)**
  - **Take isocontour of the function f(x,y,z) to get a stream surface.**

Streamballs — Overview

- Based on meta-balls
- Implicitly generated surfaces
- Easily split and merge
- Computationally expensive
- Need fine meshing to do accurate isocontouring



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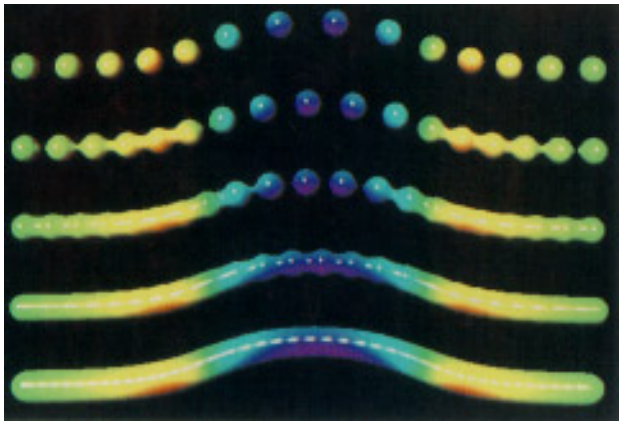
StreamBalls — Specifics

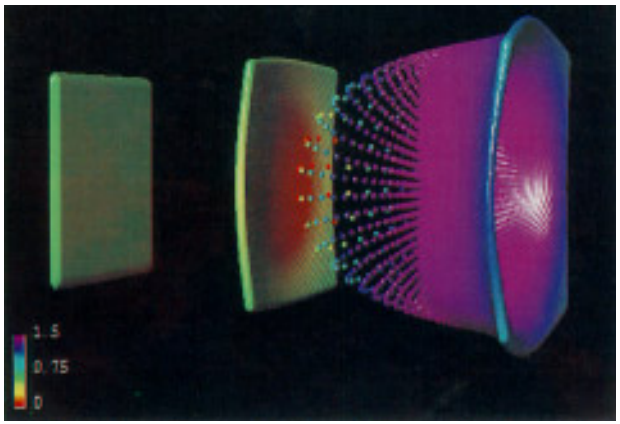
- Basic idea is to create a continous function f(x,y,z).
- And take isocontours of this function.
- Use metaballs to generate this function.
- Metaballs were developed separately by Nishimura, Blinn, and Wyvill.
- They were further refined by Bloomenthal and Shoemake.
- Treat particles as metaballs or use a timeline curve.

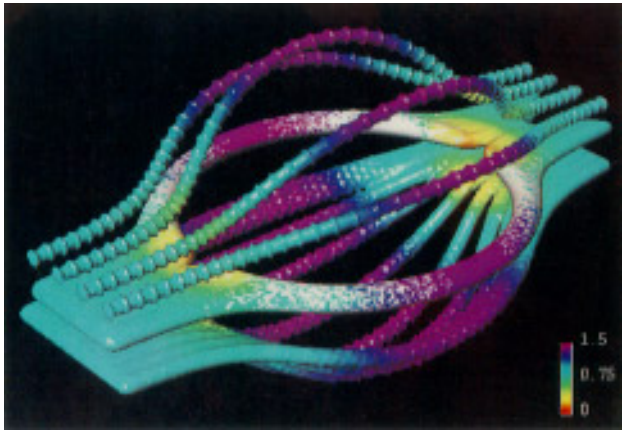


Images courtesy of Hans Hagen. Reprinted from Proceedings Visualization '94.

Streamballs — Specifics

- A rake of particles will start out as a stream surface.
- Other variables can easily be mapped to the surface's color and texture.
- Other variables can control the shape of the resulting contour surface.





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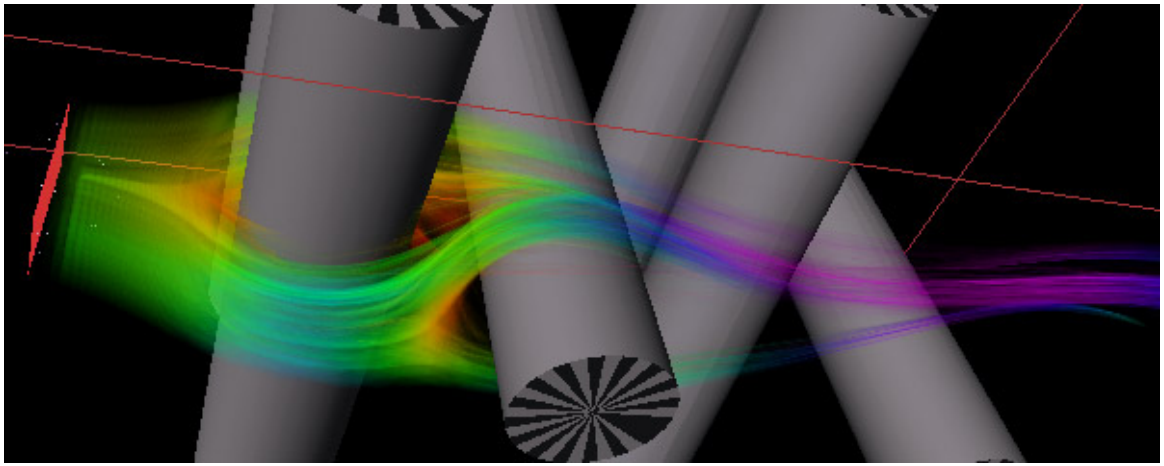
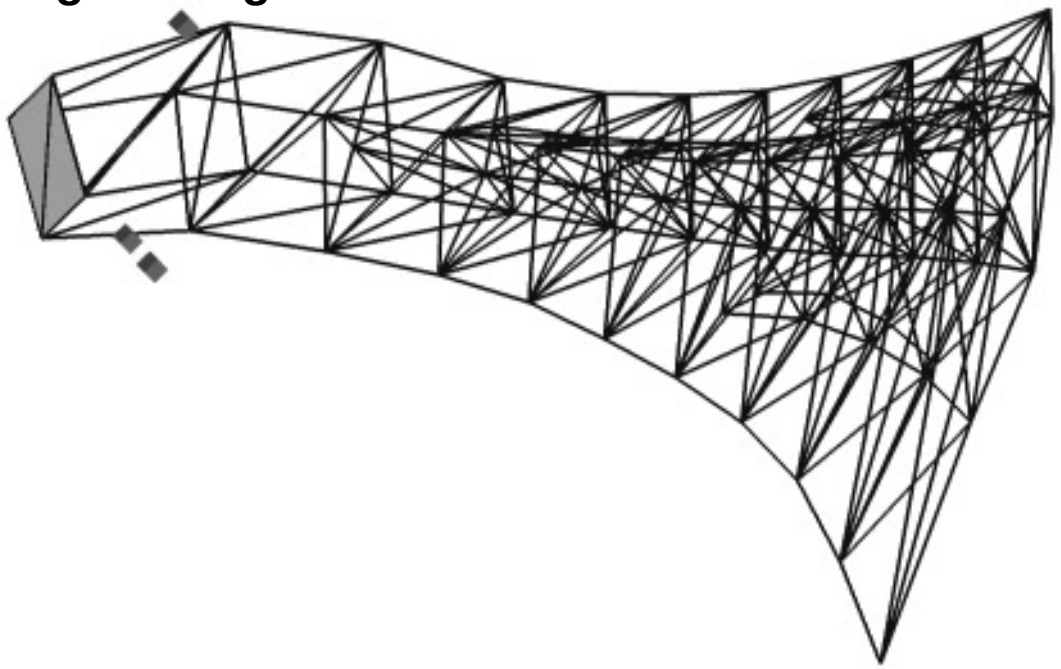
Flow Volumes — Overview

- Construction of the flow volume
- Volume rendering and compressibility
- Advection through various mesh topologies
- Puffs and colored flow volumes
- Unsteady Flow Volumes



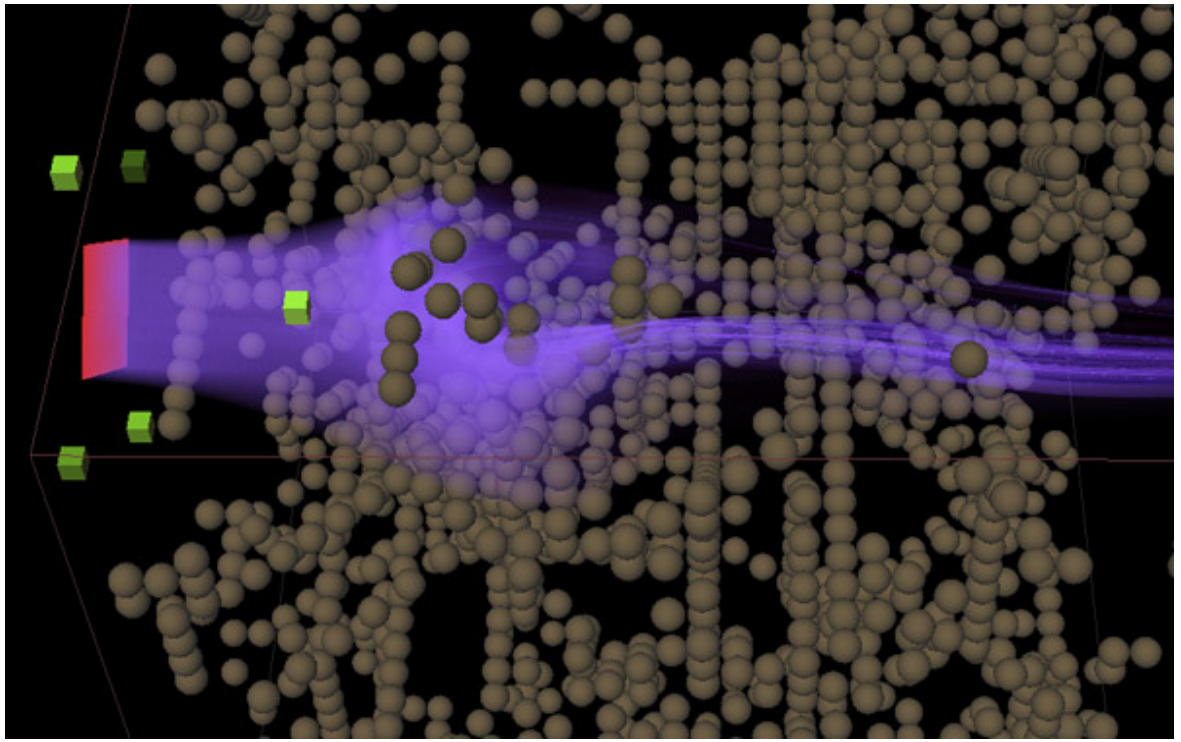
Flow Volume — Specifics

- Seed polygon (square) is used as smoke generator.
- Constrained such that center is perpendicular to flow.
- Square can be subdivided into a finer mesh.
- Like explicit stream surfaces, the volume is adaptively subdivided in areas of high divergence.
- There is no merging.



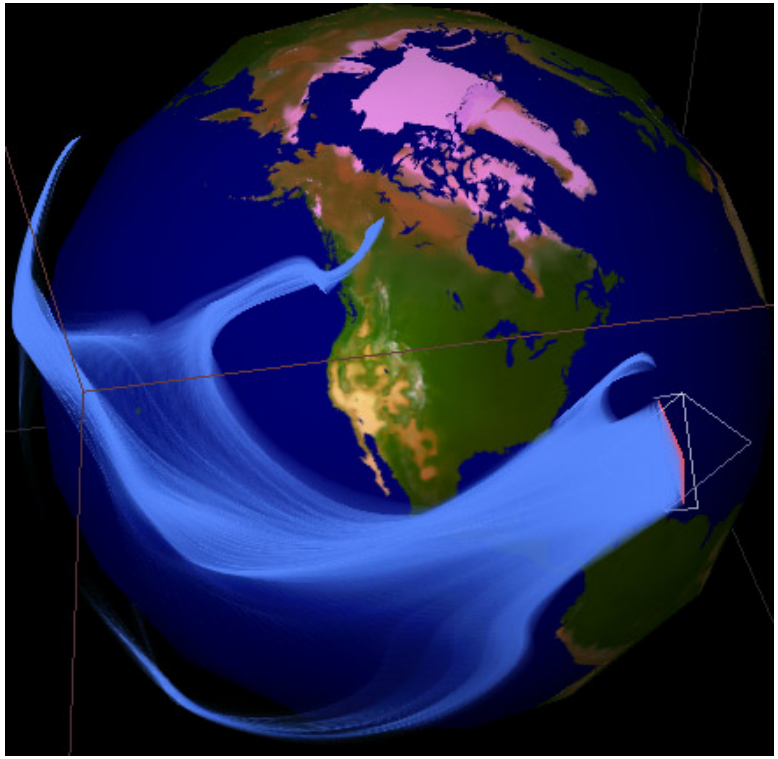
Flow Volumes — Specifics

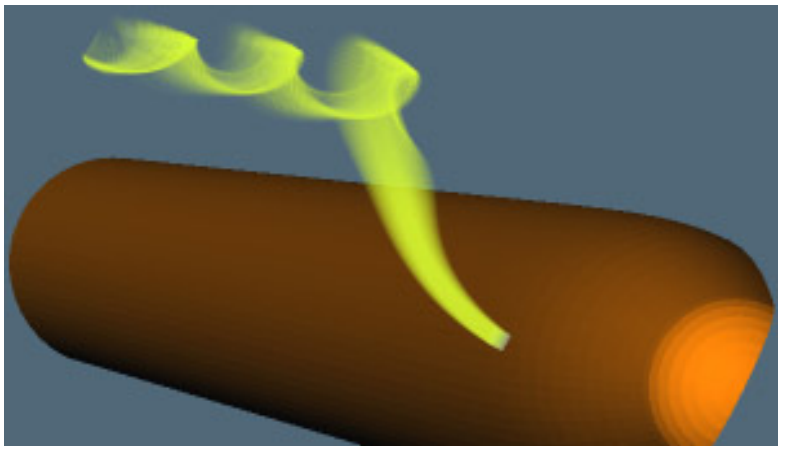
- **Volume rendering is fast due to:**
  - **Hardware assisted tetrahedra rendering**
  - **Constant colored smoke doesn't require sorting.**
- **Compressibility option highlights converging areas.**
- **Opacity is inversely proportional to the tetrahedra's volume.**



Flow Volumes — Specifics

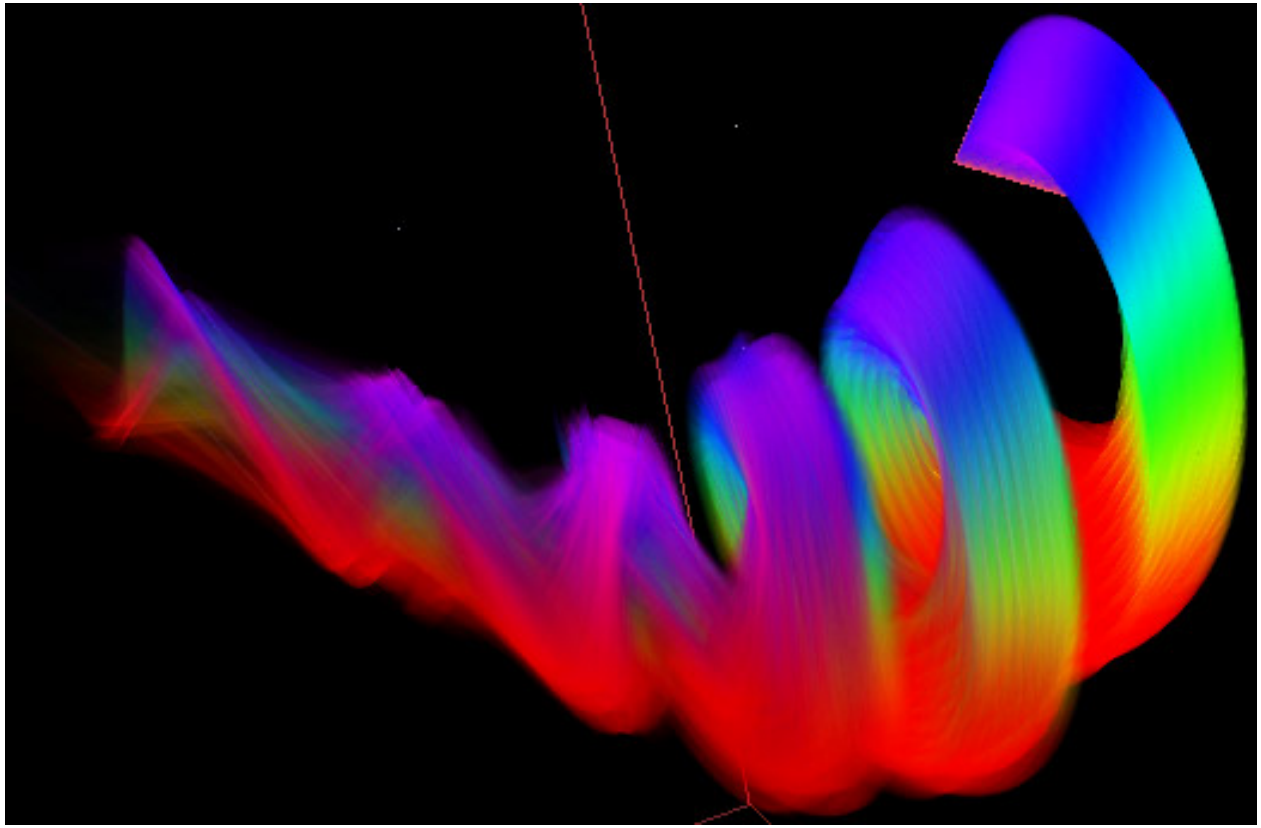
- **Object-oriented framework allows the flow field to be defined on many mesh topologies.**
- **Currently defined for regular, rectilinear, curvilinear, multigrid and unsteady meshes.**





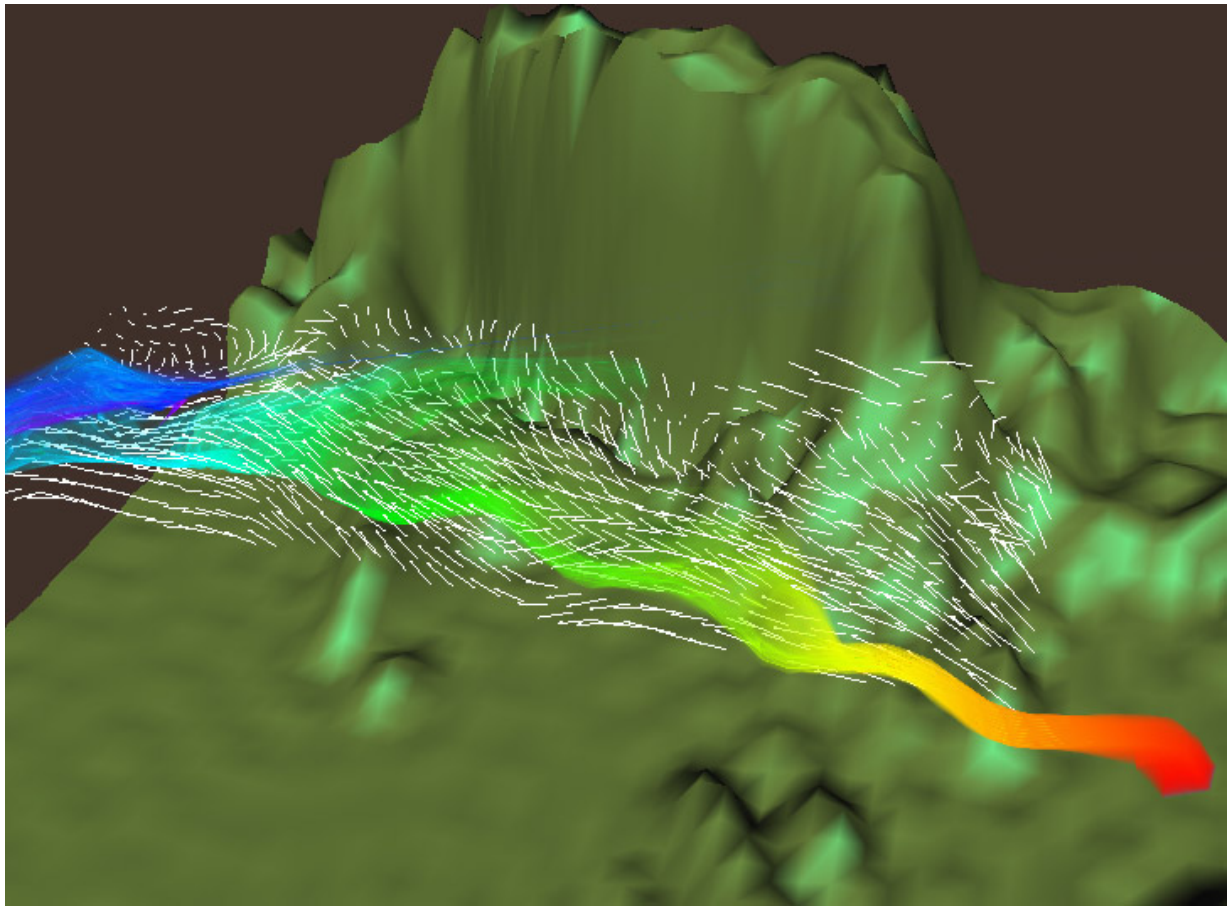
Flow Volumes — Specifics

- **Can simulate puffing smoke**
- **Flow volume can be color-coded to represent other fields.**



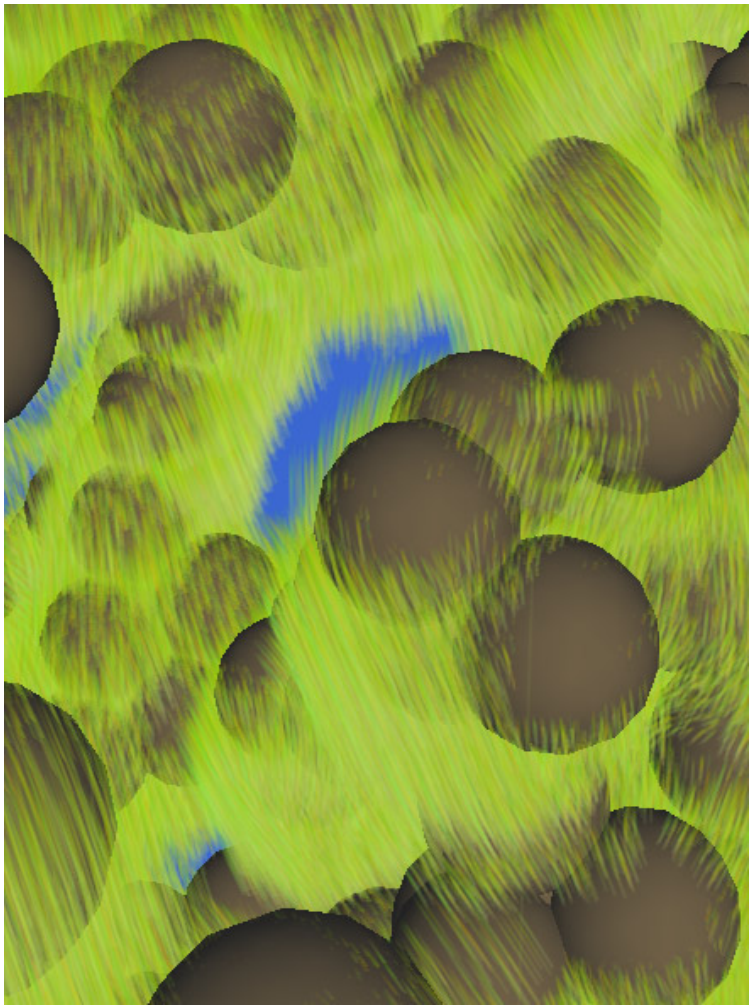
Flow Volumes — Unsteady

- **Recently extended to unsteady flows for all mesh types.**
- **Complex twisting needs to be handled well.**



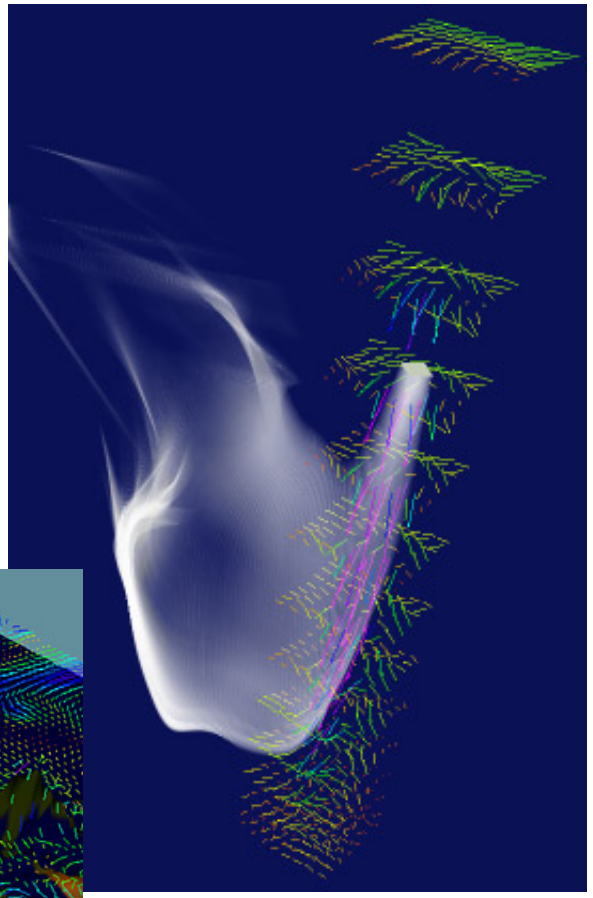
Global Techniques

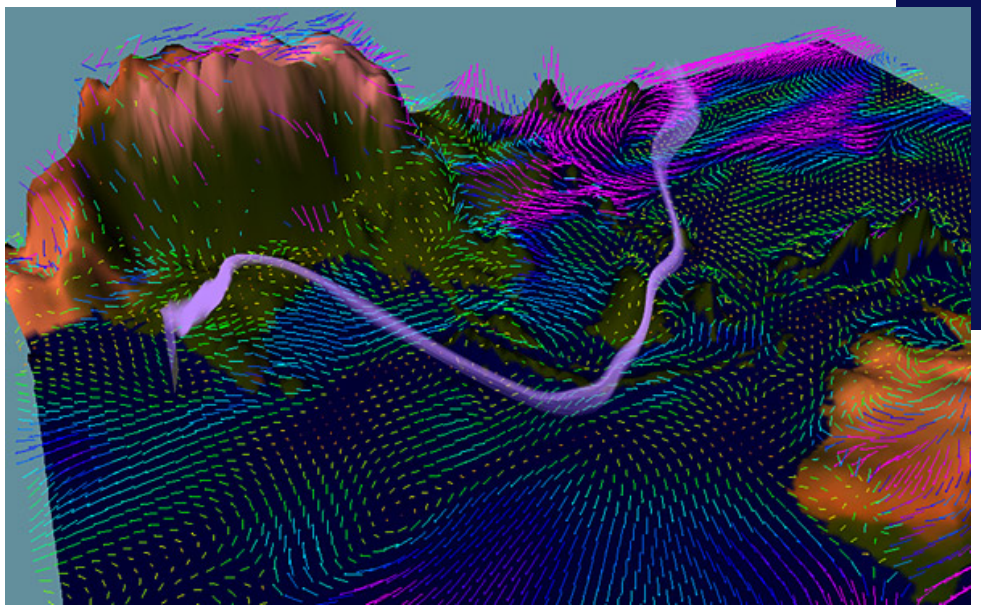
- Hedgehogs
- Vector Filter
- Line Integral Convolution
- Spot Noise
- Line Bundles
- Textured Splats



Hedgehogs

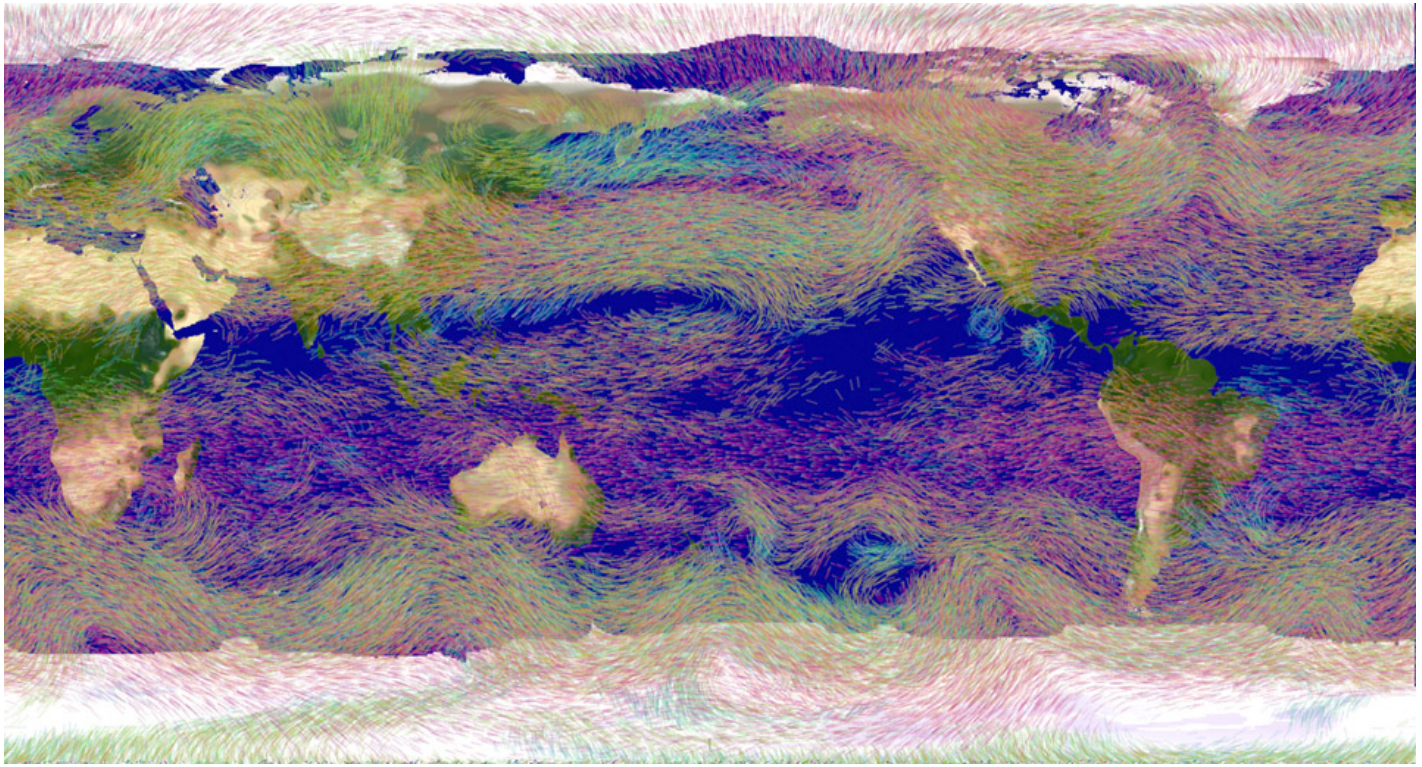
- Useful for 2D slices
- Regular patterns can be misleading
- Too much clutter for 3D fields





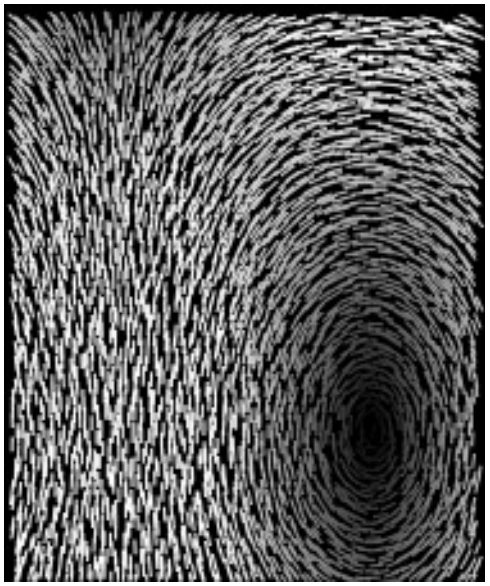
Vector Kernel for Volume Rendering

- **Sampled space in back-to-front order**
- **Image reconstruction kernel for a scalar field**
- **Anti-aliased line for a vector field**



Vector Kernel

- Build up compositing layers in back-to-front order.
- For each layer, pass vector kernel over entire image plane.
- This kernel moves in a discrete and jittered path left to right and top to bottom.
- The kernel samples the scalar and vector fields.
- The vector field uses a weighted probability of drawing an antialiased line across the kernel.



- The line is oriented in the vector field direction.
- The probability is proportional to the vector magnitude.

Line Integral Convolution (LIC)

- **Given: vector field and texture image**
- **Output: colored field correlated in the flow direction**
- **Texture image is normally white noise.**

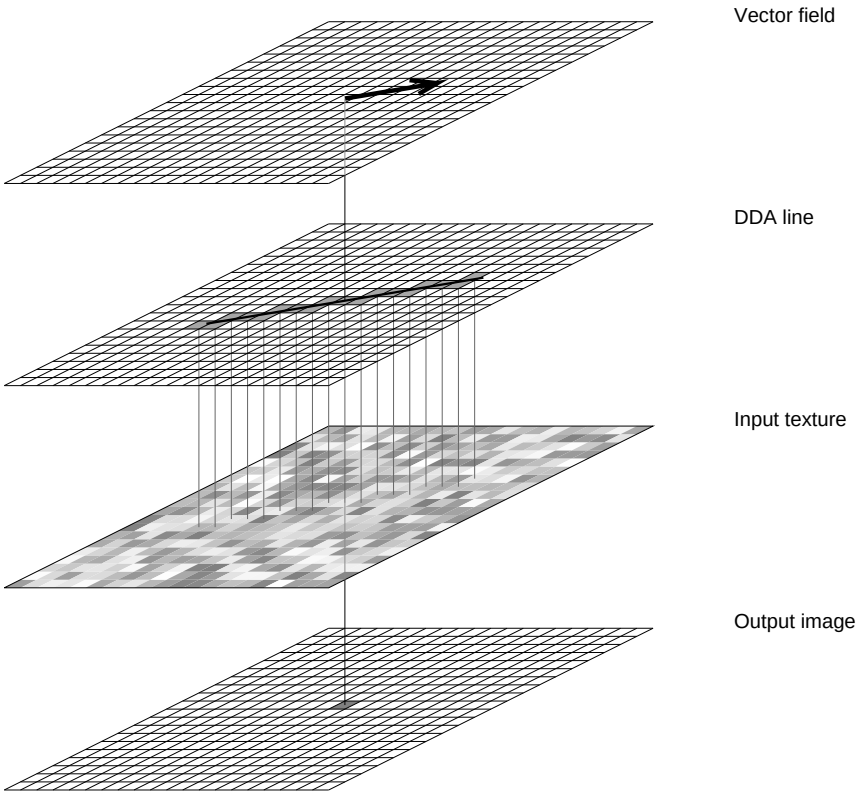


Image courtesy of Brian Cabral.

LIC — Specifics

- **Assume input texture, vector and output images are all the same resolution.**
- **For each output pixel/voxel, generate a streamline both forwards and backwards of a fixed length.**
- **Integrate the intensity that the streamline passes through.**

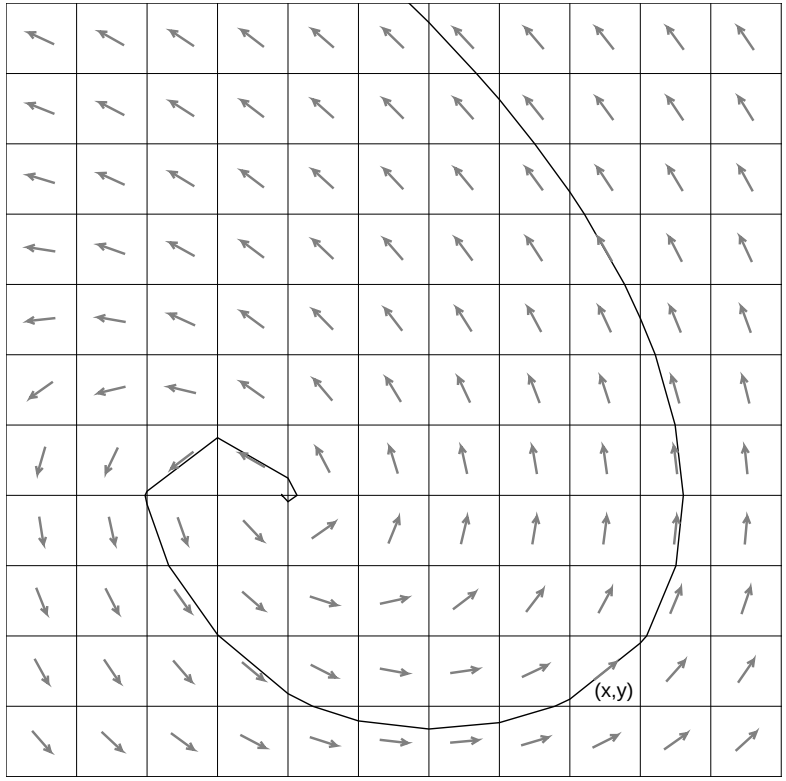


Image courtesy of Brian Cabral.

LIC — Specific

- **A convolution integral with a windowing function can be used rather than the raw integration (a weighting function).**
- **A phase shifted Hanning window allows a smooth and continous animation.**

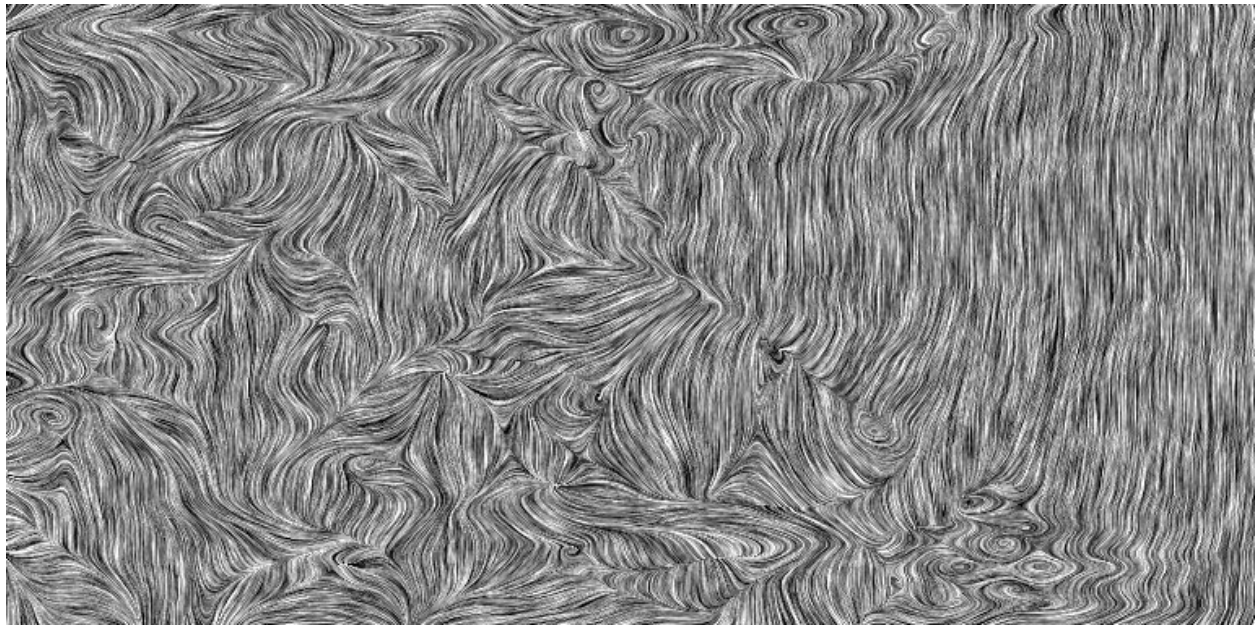


Image courtesy of Brian Cabral.

LIC — Specifics

- **LIC is dimension independent and works equally well for 3D.**
- **The resulting high-resolution colored volume resulting from LIC must then be rendered.**
- **The kernel integration can also be costly.**

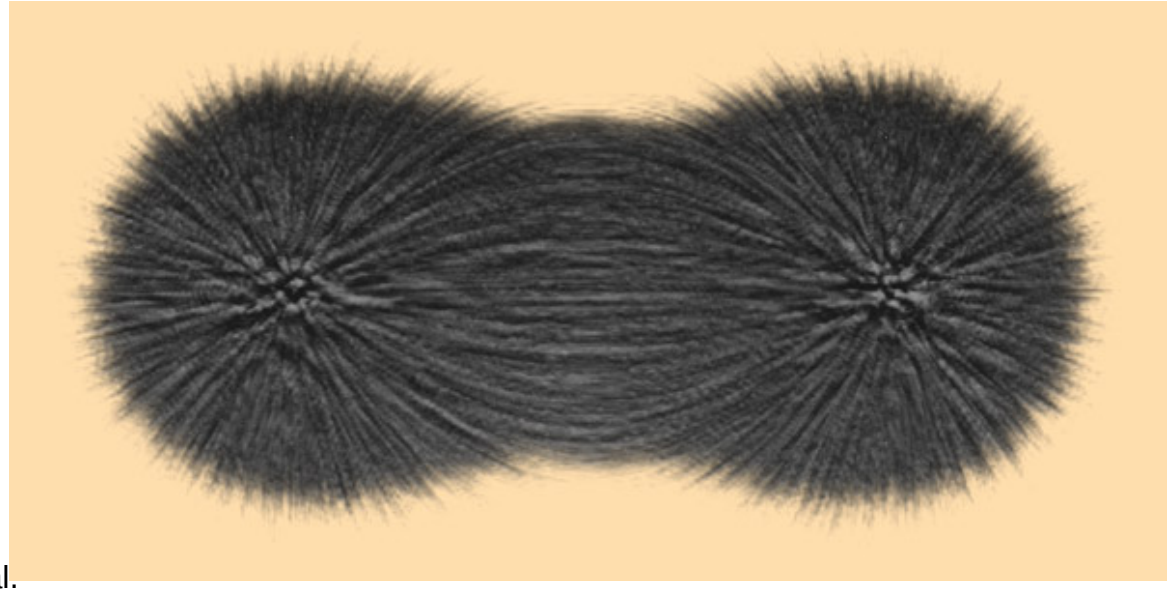
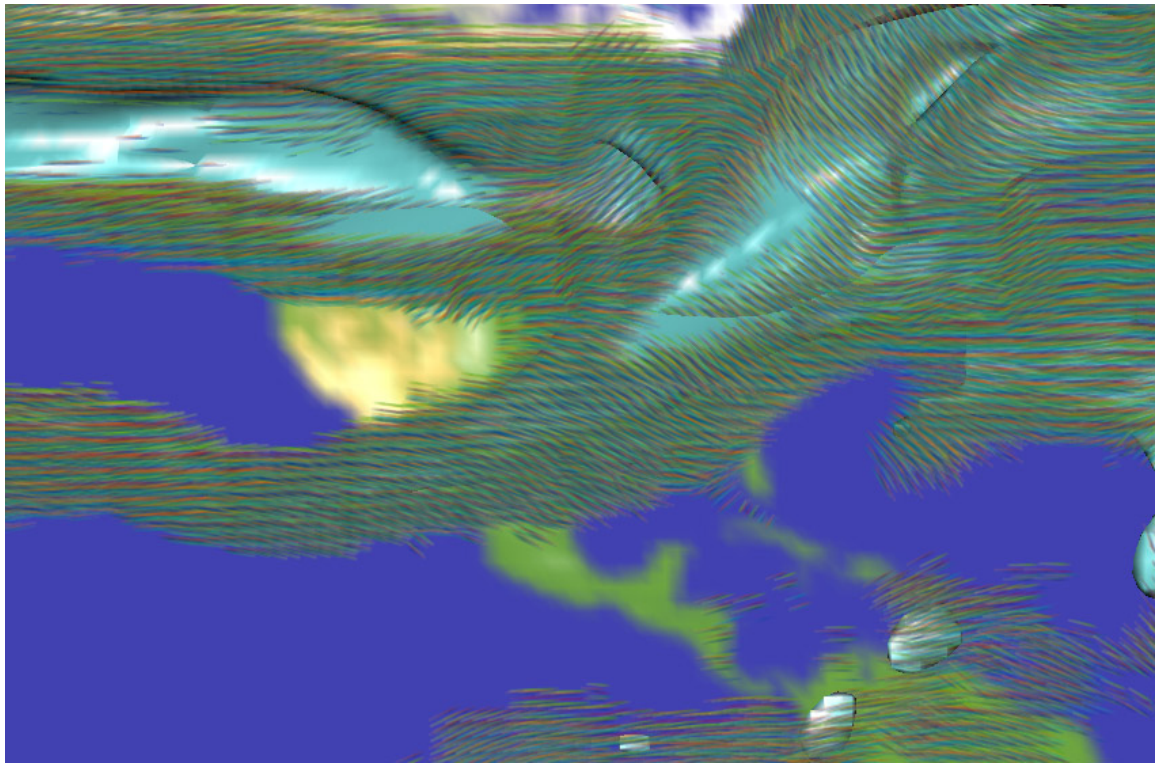


Image courtesy of Brian Cabral.

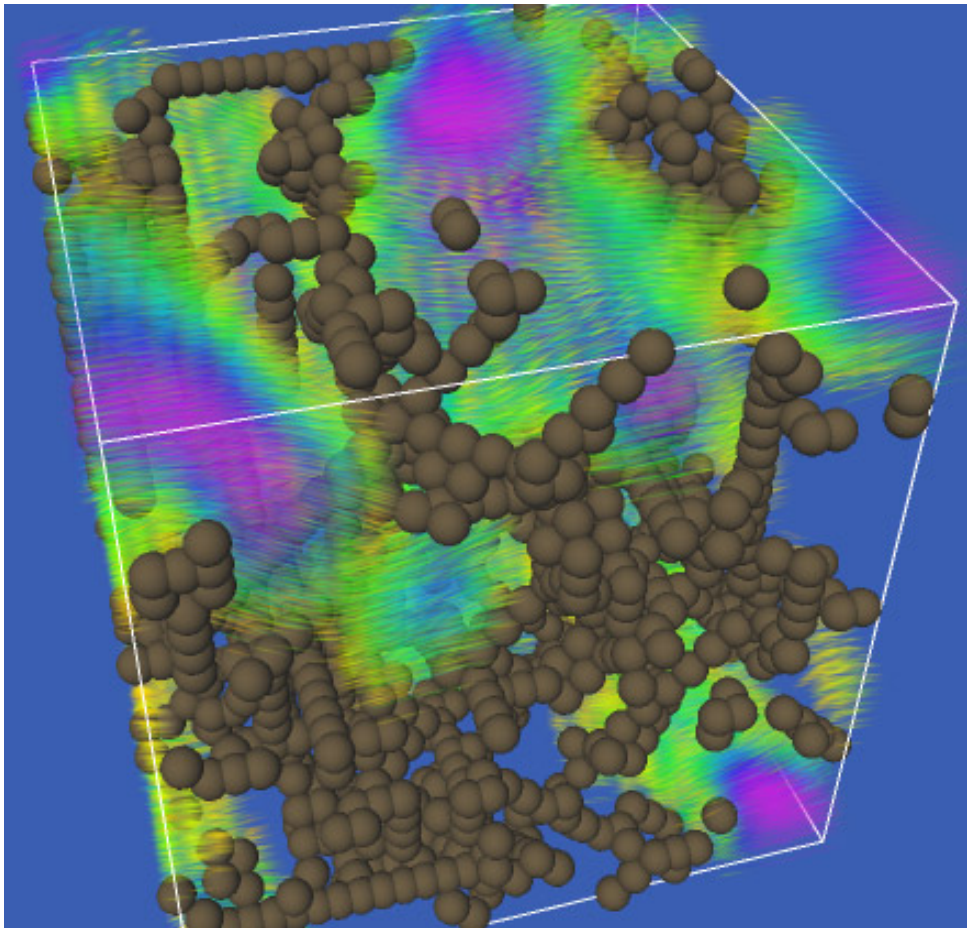
Line Bundles or Line Splats

- **Basic Idea: Create an anisotropic texture.**
- **A set of lines (a line bundle) is created such that:**
  - **Color of each line is jittered**
  - **Center of each line is randomly placed within unit cube.**
  - **All lines are oriented in the same direction.**
- **Very Fast**



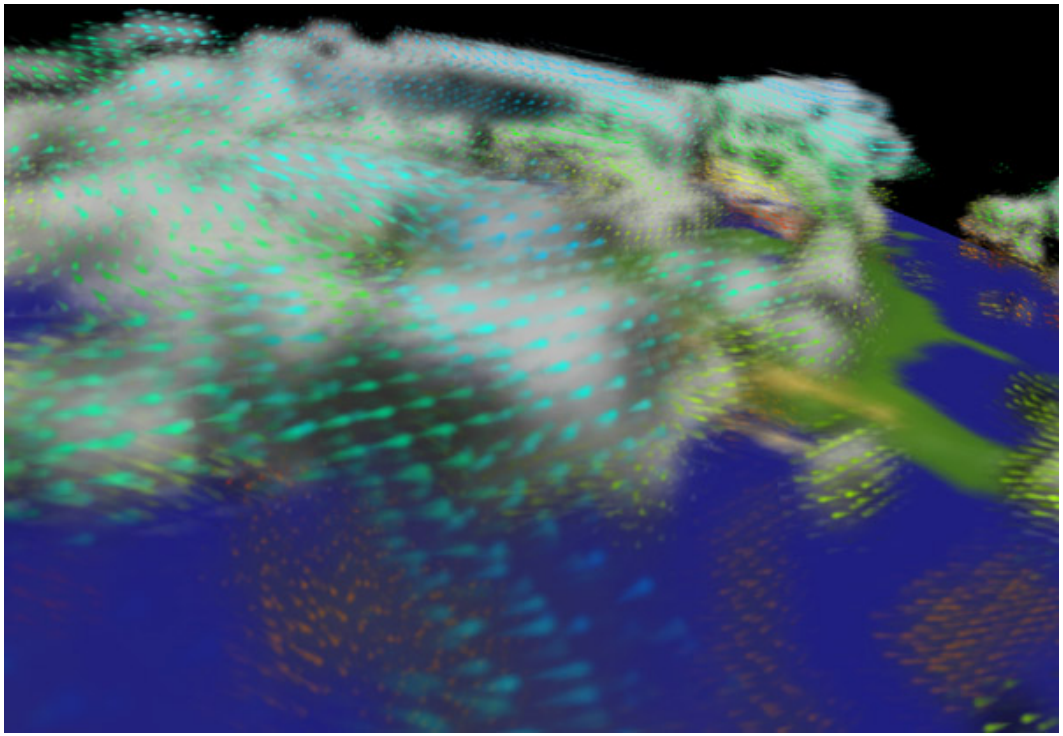
Line Bundles — Specifics

- A line bundle is drawn for each data point in back-to-front order (much like splatting).
- The line bundle is oriented in the direction of the flow at that point.
- The line bundles are allowed to overlap to yield a smooth texture.
- The composited set of line bundles produces an image representing an anisotropic volume density cloud.



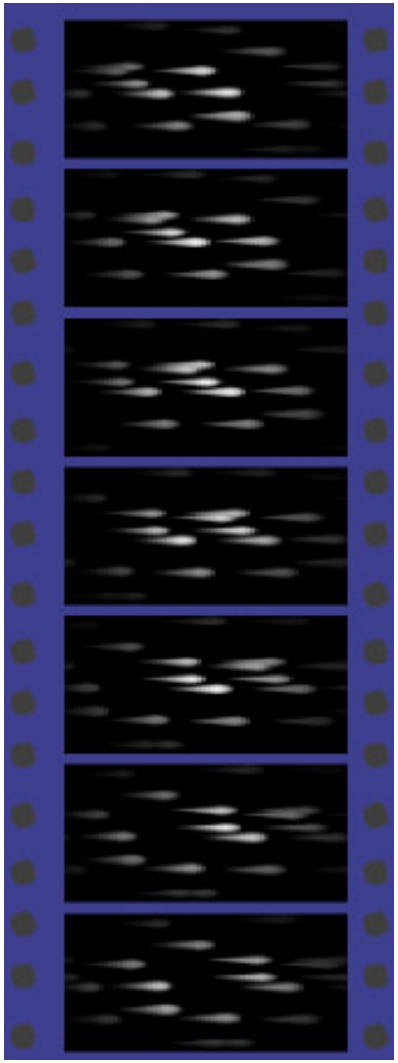
Textured Splats

- **Basic Idea:**
  - **Map reconstruction footprint from splatting to a 2D textured square.**
  - **Add anisotropic “scratches” to the texture.**
  - **Splat textures oriented in the projected direction of the flow.**
  - **The back-to-front compositing yields a volume rendering with vector icons embedded.**



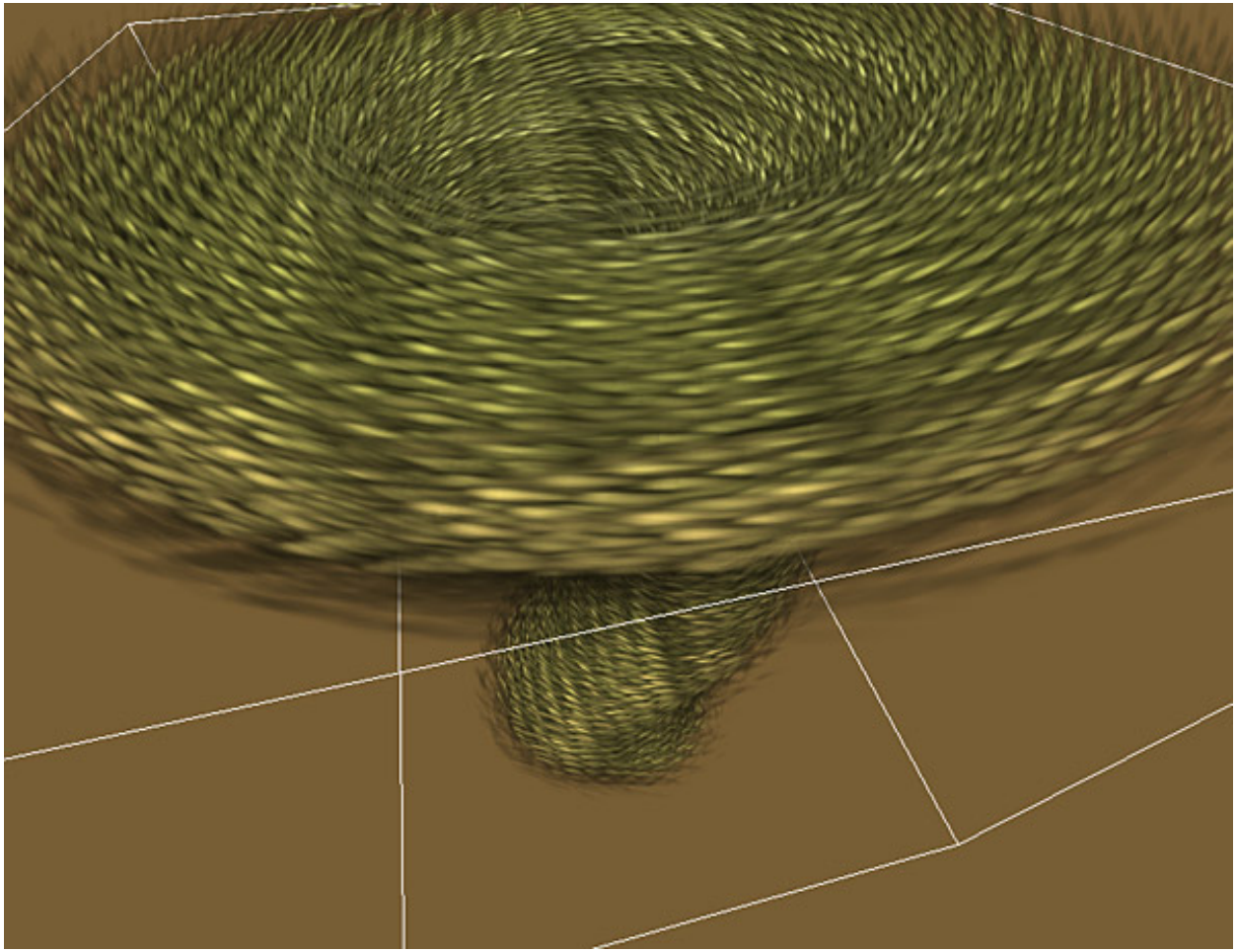
Textured Splats — Specifics

- **A set of textures can be constructed for animation.**
- **The vector icons are cyclically shifted before being windowed.**



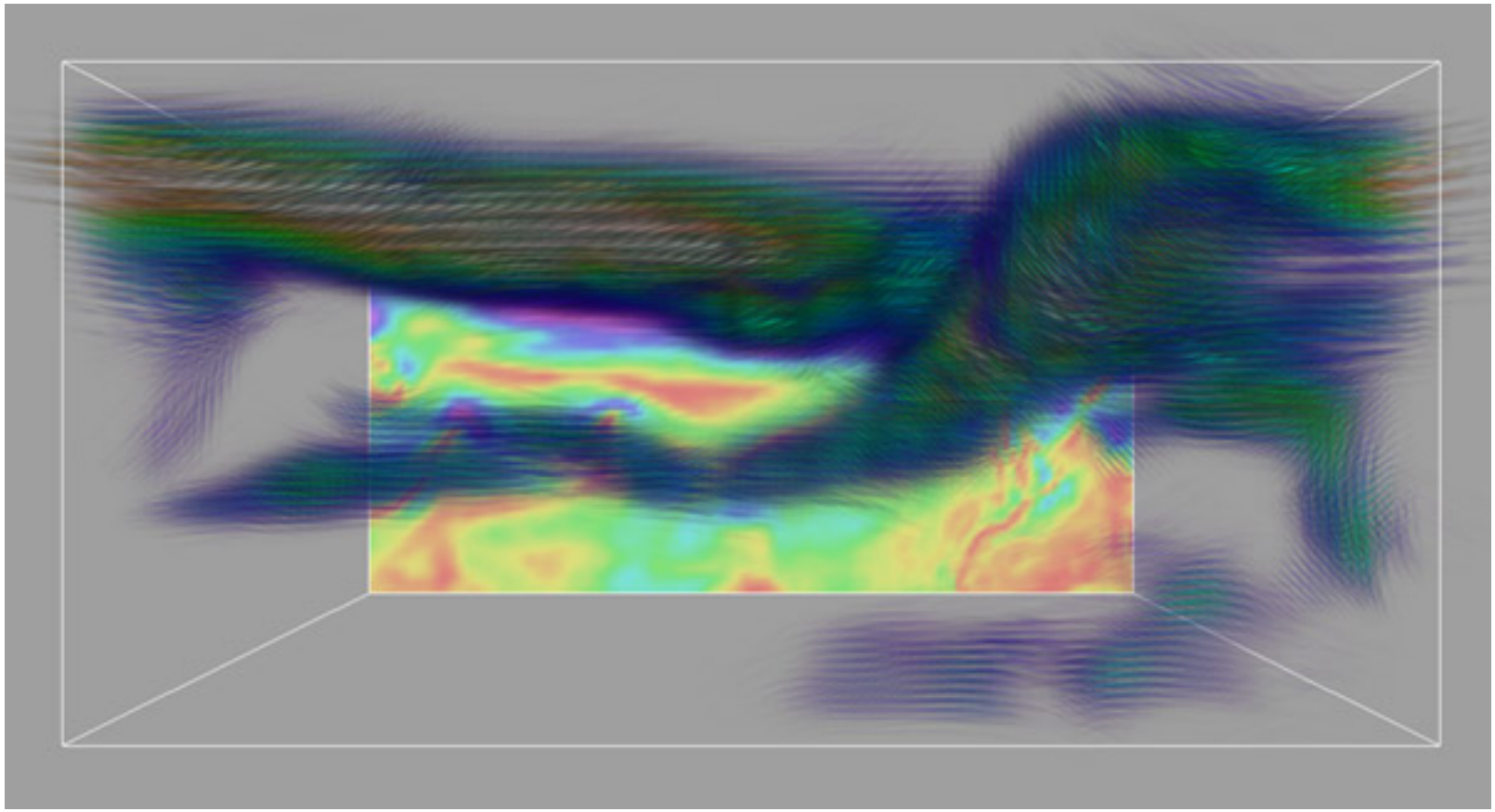
Textured Splats — Specifics

- **The textures can be used without the scalar reconstruction to construct an anisotrpoic volume.**



Textured Splats — Specifics

- **The vector icons can be stretched in the vector direction to construct a brushed-like volume.**



Classification of Critical Points

- **Determine points where velocity vanishes - the critical points.**
- **Catergorize these points based on surrounding flow: source, sink, saddle, spiral saddle, etc.**
- **Represent different types of critical points with different icons**
- **Connect the critical points for a global view of the field**

Critical Points

- **The eigenvalues of the matrix of partial derivatives of the velocity determine the type of a critical point.**

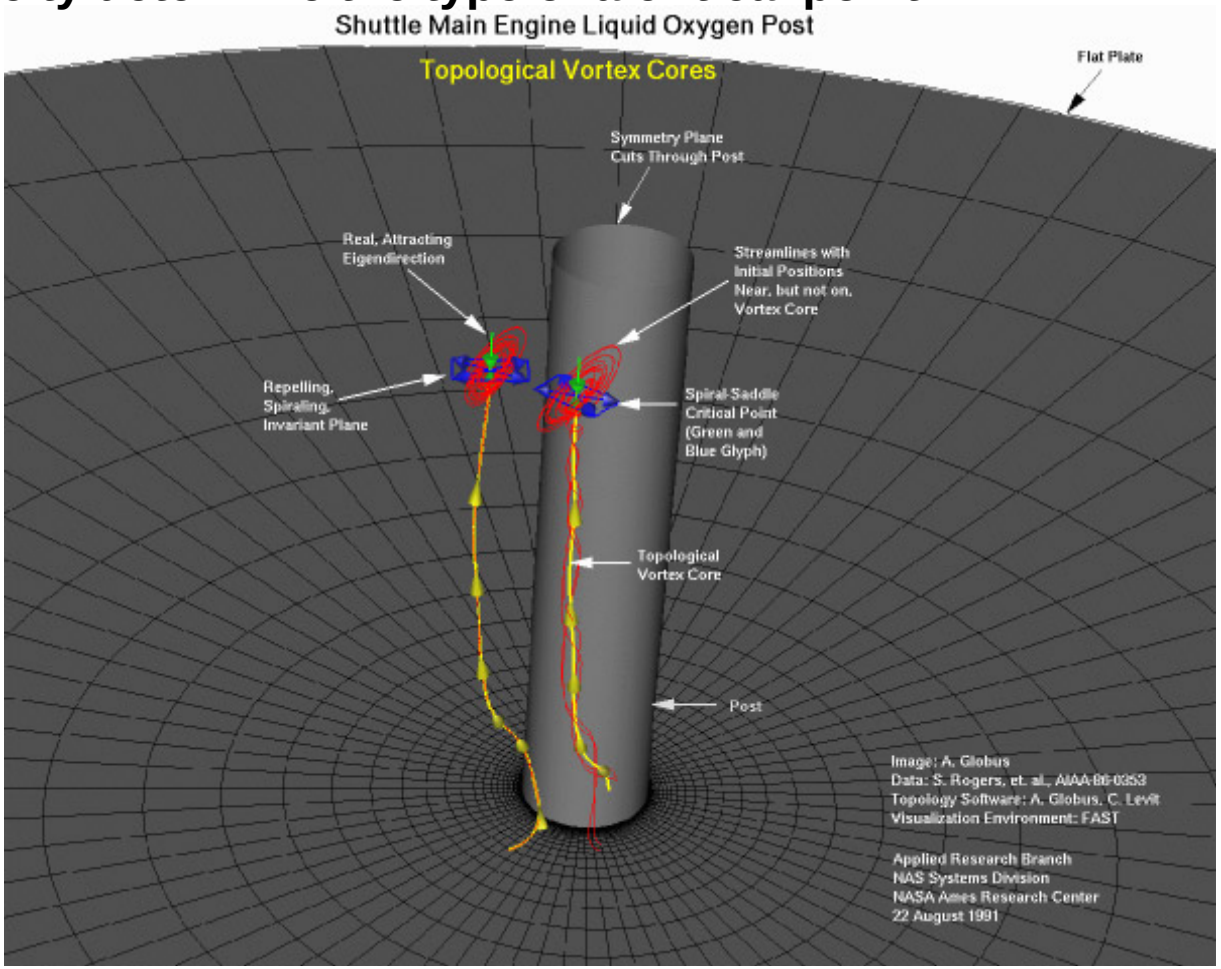
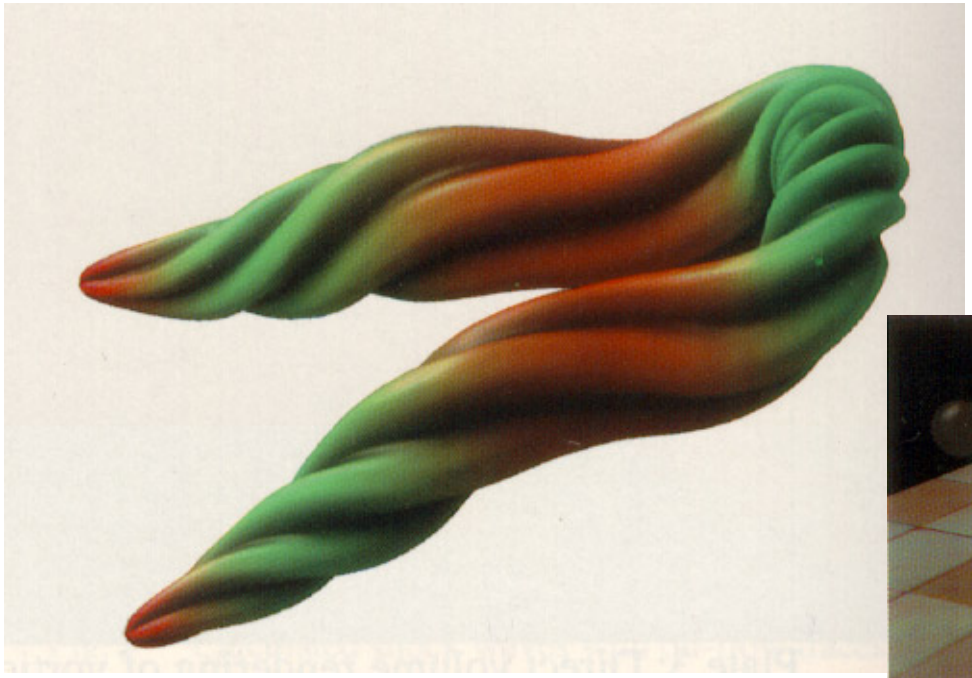
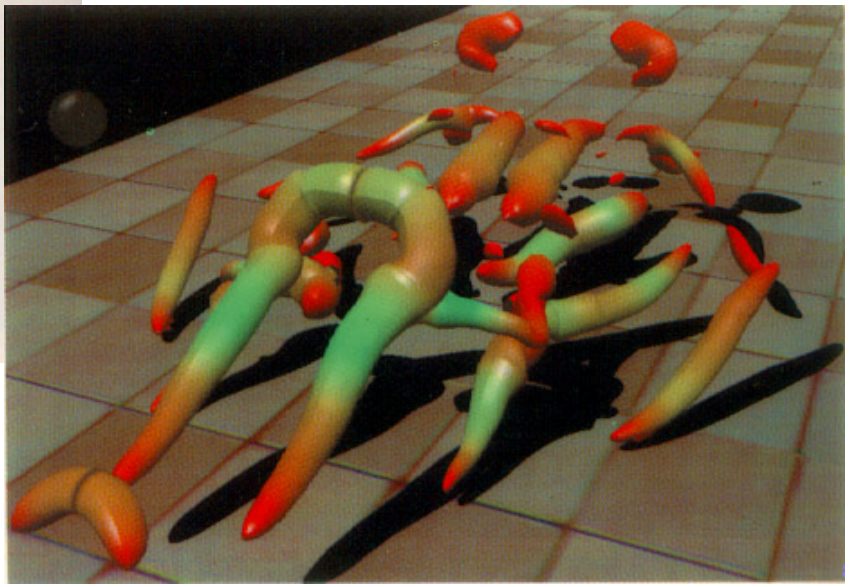


Image courtesy of Al Globus, NASA

Vortex Cores

- **Determining and representing vortex cores has been explored by several researchers**

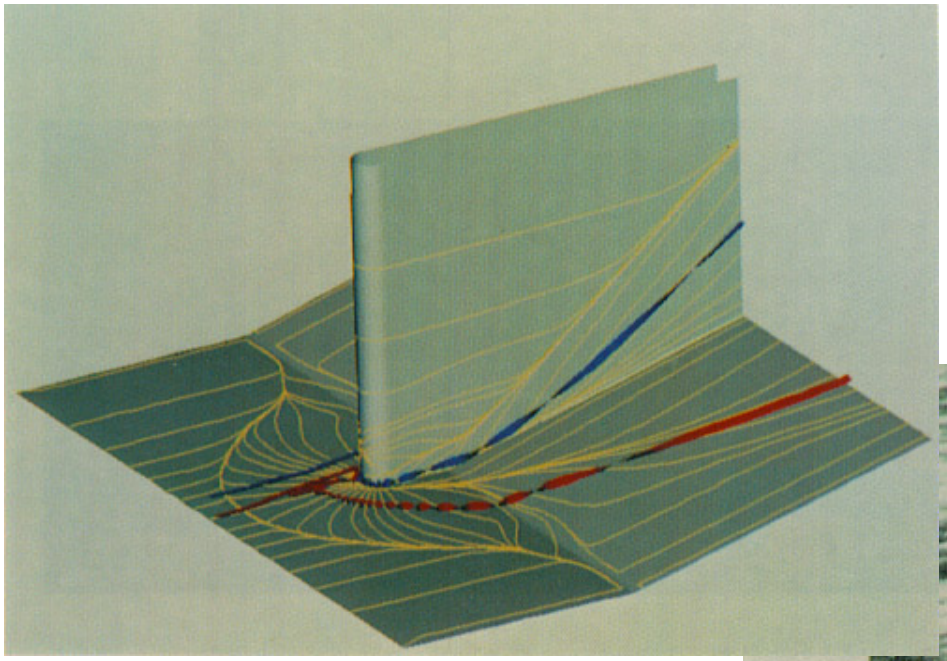


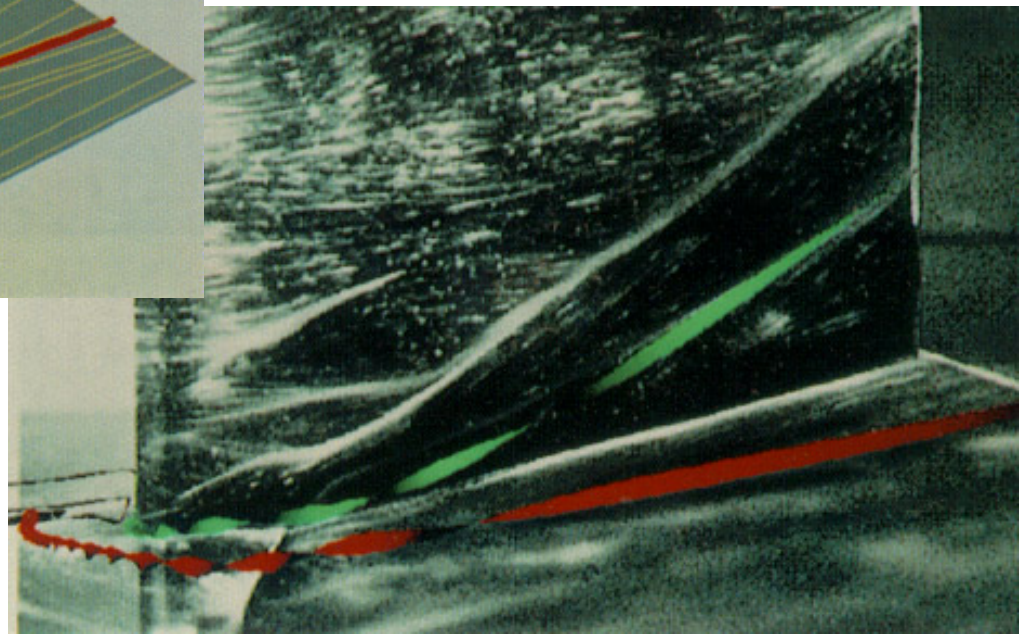


Images courtesy of David Banks.
Reprinted from Proceedings Visualization '94.

Skin-Friction Lines

- **Skin-friction lines and other features can also be identified.**





Images courtesy of H. Pagendarm, DLR.

Summary

- **Cost of integration for thousands of points can be expensive**
- **For global methods using volume rendering, sorting can be expensive for non-regular data sets.**
- **Streamlines, etc. give a more quantitative representation, though only locally.**
- **Texture methods give a more global view, though qualitative.**
- **Solution: use texture techniques to determine areas to investigate further with advection techniques.**
- **Combine texture methods with classification methods.**

Further Reading

- [1] Banks, D.C. and B.A. Singer. Vortex Tubes in Turbulent Flows: Identification, Representation, Reconstruction. in Visualization '94. 1994. Washington, D.C.: IEEE Computer Society Press.
- [2] Becker, B.G., D.A. Lane, and N.L. Max. Unsteady Flow Volumes. in Visualization '95. 1995. Altanta, Georgia: IEEE Computer Society Press.
- [3] Brill, M., et al. Streamball Techniques for Flow Visualization. in Visualization '94. 1994. Washington, D.C.: IEEE Computer Society Press.
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Acknowledgements

- Barry Becker and Nelson Max developed most of the software for the Flow Volumes.
- The Global Climate data is courtesy of the PCMDI program at LLNL.
- The NASA data sets are courtesy of David Lane, NASA Ames.
- The aerogel data is courtesy of Tony Ladd and Elaine Chandler.
- The HEPA filter data is courtesy of Bob Corey.
- The Groundwater data is courtesy of Steve Ashby.
- Funding for this research is through the LDRD program, LLNL.